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WHITE OAK LABORATORY

A COMPONENT RELIABILITY MODEL FOR BOMB FUZE MK 344 MOD 1 AND MK 376 MOD 0

By
Edgar A. Cohen, Jr.
Ronald Goldstein

12 AUGUST 1975

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The purpose of this report is to present a general reliability model for either the Mk 344 Mod 1 or Mk 376 Mod 0 fuze, taking into account the interrelations among the components in the actual schematic of the fuze. Using recent data, provided by Fairchild Defense Products, a reliability model was designed which takes into account component failures. The reliability and confidence levels predicted by this model are in complete agreement with those obtained from simulated test drop data on total number of successful firings.

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KURT R. ENKENHUS
By direction

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INTRODUCTION

We present a reliability model for a fuze of the Mk 376 Mod 0 type, of which the Mk 344 Mod 1 can be considered a special case, as will be indicated. Previous reliability studies[1] for the laboratory have considered the fuze as an entity in a reliability model involving other components on the aircraft. This report takes a closer look at the components of the fuze itself, and we present a model of the fuze based on such a detailed analysis. In addition, we show that the reliability and confidence intervals are in complete statistical agreement with those obtained from simulated test drop data which only indicated the number and percentage of successful firings.

DISCUSSION

For our purposes we shall assume a binomial distribution type process, that is, we assume that each essential component in the network works or does not work with a certain probability. We therefore think of the system as a set of components, c_i, each of which is associated in 1-1 correspondence with a random variable X_i. This random variable X_i is assigned the value 1 if c_i works and 0 otherwise. If the fuze is to operate effectively, each component must do its job. In a sense, effectiveness should be considered as an important part of reliability analysis.

MODEL FORMULATION

Figure 1 is a block diagram of the Mk 376 Mod 0 fuze. We shall consider each block in this diagram as a component. Therefore, if any element of component c_i fails, we shall say that c_i itself has failed. Figure 2 is a circuit diagram of the fuze and shows in detail all the items involved in what we presently consider components. Let us designate the components in the following manner:

[1] P. S. Bergh, R. G. Broadwell, W. R. Jenkins and C. K. Smith, All-DC Electric Bomb Fuze System, A Study of Reliability, Safety, and Maintainability, TR 01417.01-1, Vitro Laboratories, Silver Spring Laboratory, July 1970.

Component Number	Component
0	Option Circuit
1	Switch SW-1
2	Switch SW-2
3	Rectifier and Regulator
4	Arming Switch (2)
5	Impact Switches or Mk 43 Target Detecting Device
6	Detonator
7	Switch SW-4
8	Energy Storage A (Arming and Detonation)
9	Energy Storage D (Detonation)
10	Function Timer
11	Arming Timer T_{A1}
12	Arming Timer T_{A2}
13	Bellows
14	Mk 31 Safety Device
15	Switch SW-3
16	Dudding Switches

In addition, to take account of such things as faulty interfaces between blocks or undecidable occurrences, we shall incorporate these statistics into a factor f which will represent a fictitious component we call the compensating factor. We define the reliability of a component to be the probability that it works, i.e., $p(c_i) = p(X_i = 1)$. (Please see Appendix for a convenient table listing the components, the probability symbols used here, and the computed probabilities for these components). In the case of the Mk 376 Mod 0, there are two timers, the first of which operates nominally for 2.6 seconds and the second of which operates nominally for 7.4 seconds[2]. There is here the option of either retarded or unretarded arming. In contrast, retarded arming is not present in the Mk 344 Mod 1, but, instead, the total arming time is designed to be 5.5 seconds within a certain tolerance given in the specifications[3].

There are two logical paths in this network which display the flow and interdependence of the various components leading to detonation. They are the instantaneous mode-path PA_1 and the delay mode-path PA_2, as indicated in Figure 3. Please note that the arming circuit is displayed as one box in this flow diagram. Figure 4 gives the details of the arming circuit. The two possible paths in the arming circuit diagram correspond to retarded or unretarded mode operation. Note that, in the Mk 344 Mod 1 fuze, the

[2] Aircraft, Bombs, Fuzes, and Associated Components, Technical Manual, NAVAIR 11-5A-17, U-270394, 1 July 1973, published by direction of the Commander, Naval Air Systems Command.

[3] Purchase Description, Fuze, Bomb, Mark 344 Mod 1, AS2677, U.S. Naval Ordnance Laboratory, White Oak for Naval Air Systems Command, 6 July 1972, E. T. Ward, by direction.

retard path is simply not present. In either case, p_A, the probability of arming, is given by the sum of the probabilities of successful completion of the two arming paths minus the probability of successful completion of their common part. Therefore,

$$p_A = p_8 \, p_{11} \, p_{12} \, p_{13} \, p_{14} \, p_{15} \, p_{16} + p_8 \, p_{11} \, p_{13} \, p_{14} \, p_{15} - p_8 \, p_{11} \, p_{13} \, p_{14} \, p_{15}$$

$$= p_8 \prod_{i=11}^{16} p_i .$$

For our mathematical model, we define the reliability of the system to be the probability of successful detonation, that is, the probability of successful completion of the instantaneous mode-path PA_1 plus the probability of success of the delay mode-path PA_2 minus the reliability of the components common to the two paths. In symbols, using R for reliability and P for probability of success, we have

$$R = R(PA_1 \cup PA_2) = P(PA_1) + P(PA_2) - R(PA_1 \cap PA_2).$$

If we assume independence of components, the reliability is then given by the relation

$$R = p_f \, p_o \, (p_1 \, p_3 \, p_A \, p_4{}^2 \, p_5 \, p_6 + p_1 \, p_2 \, p_3 \, p_A \, p_4{}^2 \, p_5 \, p_6 \, p_7 \, p_9 \, p_{10}$$

$$- p_1 \, p_3 \, p_A \, p_4{}^2 \, p_5 \, p_6) = p_f \, p_o \, p_1 \, p_2 \, p_3 \, p_A \, p_4{}^2 \, p_5 \, p_6 \, p_7 \, p_9 \, p_{10},$$

where

$$p_A = p_8 \prod_{i=11}^{16} p_i .$$

Therefore,

$$(1) \quad R = p_f \, p_4 \prod_{i=0}^{16} p_i .$$

In the case of the Mk 344 Mod 1, where there is no retard option and therefore only one arming timer, the reliabilityis only slightly altered. The only difference here is that switch SW-3 and the dudding impact switches are not present and that we take Timer TA_2 (represented by c_{12}) to be the arming timer. Thus, in our formula 1, we simply set $p_{11} = p_{15} = p_{16} = 1$ to take account of the absence of the corresponding components.

CONCLUSION

Although it is true that a finer analysis of the fuze from the point of view of its components does not yield substantially different results as far as overall reliability and confidence intervals are concerned (see appendix for details), it is felt that this "finer grain" analysis is needed to understand the underlying causes of failure. We plan to investigate the possibility of including redundant components in the system to improve reliability, subject to cost and size restrictions. This will be the subject of our next report. Noting that the lower bound on the confidence interval for reliability is at most 91% (see appendix), it is felt that some improvement in the manufacture and assembly of the fuze is in order if one wants an operability of 93% or better.

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The authors would like to thank Mr. George Klamm and Dr. Kenneth Shere for their helpful support of this project. Also, we would like to acknowledge the help of Messrs. Ray Houghton, Dean Jensen, and Larry Burkhardt, who provided data and assistance in understanding the operation of fuzes Mk 344 and 376.

TABLE 1
FAIRCHILD FUZE MK 344 MOD 1 FAILURE MODES

ITEM NO	FUZE LOT NO	NO. F[illegible] NO.	FAB DATE	TEST DATE	TYPE CONDIT TEST	FIRING VOLTAGE	TYPE OF FAILURE	ARM TIME (SEC)	FAULTY PART	REMARKS
1	11-001	5	[illegible]	9-72	THERMAL SHOCK	-300	OPTION LG ARM	6.28	MK 127 SWITCH DUD	(1) S-2 DID NOT FIRE (2) BRIDGE RESISTANCE 28.5 OHMS (3) EXPLOSIVE ON X-RAY NOT NORMAL
2	11-001	13	6-72	9-72	VIBRA	-300	DNF		C-10 DEFECTIVE	(1) C-10 WOULD NOT HOLD CHARGE
3	11-002	49	[illegible]	10-72	VIBRA	+195	DNF		TREMBLER CIRCUIT	(1) BAD SOLDER JOINT AT WIRE #12 ON BOARD #2 (2) POOR QUALITY CONTROL
4	11-003	53	9-72	10-72	THERMAL SHOCK	-300	LG ARM	7.1		(1) S-2 NOT FIRED (2) LOW REGULATOR VOLTAGE
5	4-007	105	9-72	10-72	VIBRA	+195	FOA			(1) CANNOT BE DETERMINED (2) POST FIRED DATA NOT OBTAINED, I.E. CAPACITOR VOLT.
6	11-008	121	10-72	11-72	CONTROL	+195	DNA		MK 31 SAFETY DEVICE	(1) SD RAN SLOW – 5.5 SEC (2) BELLOWS FIRED AND MK 31 GAUGED FUZE
7	11-018A	188	1-73	1-73	VIBRA	-300	LG ARM	60.0	BRIDGE RECTIFIER CIRCUIT	(1) HIGH INPUT RESISTANCE IS CIRCUIT
8	11-018A	197	1-73	1-73	THERMAL SHOCK	-300	DNA		C-5 DEFECTIVE	(1) C-5 WOULD NOT HOLD CHARGE (2) S-1 FIRED, CAUSE UNKNOWN
9	11-018B	271	1-73	5-73	VIBRA	-300	FOA			(1) DATA INDICATES POSSIBLE MK 128 CLOSURE AND C-8 FIRED S-4
10	11-018A	284	1-73	5-73	THERMAL SHOCK	-300	DNA		CR-5 DEFECTIVE	(1) CR-5 SHORTED (2) S-2 DID NOT FIRE
11	11-020	334	1-73	5-73	VIBRA.	+195	FOA			(1) DATA INDICATE V-5 CONDUCTED AT ROTOR ARMING
12	11-021	446	1-73	9-73	VIBRA.	-300	DNF			(1) CIRCUIT DEFECTIVE (2) CANNOT COMPLETE CIRCUIT CHECK OF CR-15 AND S-4
13	12-003A	342	4-73	5-73	THERMAL SHOCK	+195	DNA		MK 127 SWITCH INSULATION	(1) S-1 BRIDGE WIRE SHORT TO BUSS #6 (2) S-4 FUNCTIONED DUE TO S-1 FAULT (3) S-4 SHOULD NOT HAVE FIRED (4) POOR QUALITY CONTROL
14	12-003A	360	4-73	5-73	CONTROL	+195	FOA		CR-19	(1) DATA INDICATE V-5 CONDUCTED AT ROTOR ARMING (2) CR-19 HAD HIGH FORWARD RESISTANCE
15	12-003B	732	4-73	10-73	THERMAL SHOCK	-300	DNF			(1) CAUSE NOT DETERMINED (2) CANNOT COMPLETE CIRCUIT CHECK OF CR-15 AND S-4
16	11-031	680	4-73	10-73	THERMAL SHOCK	-300	AOC		Q-1 DEFECTIVE	(1) Q-1 SHORTED (2) POOR QUALITY CONTROL AT COMPONENT LEVEL
17	11-032	653	5-73	10-73	THERMAL SHOCK	-300	DNA		CR-21 DEFECTIVE CR-10 DEFECTIVE	(1) CR-21 OPEN PREVENTED CHARGE ON C-8 (2) CR-10 CIRCUIT HAD HIGH RESISTANCE
18	11-032	647	5-73	10-73	VIBRA.	+195	DNA			(1) DATA INDICATE FUZE DID NOT RECEIVE CHARGE (2) CAUSE UNKNOWN
19	11-032	655	5-73	10-73	THERMAL SHOCK	+195	FOA		CR-21 DEFECTIVE	(1) DATA INDICATE V-5 CONDUCTED AT ROTOR ARMING (2) C-9 HAD LEAK PATH TO C-5 (3) POOR QUALITY CONTROL (4) CR-21 HAD LOW REVERSE RESISTANCE
20	12-006	364	5-73	6-73	VIBRA.	+195	DNA		FUZE CHARGING RECEPTACLE	(1) INTERMITTENT CONNECTION
21	12-006	375	5-73	6-73	THERMAL SHOCK	-300	DNF			(1) CIRCUIT DEFECTIVE (2) CANNOT COMPLETE CIRCUIT CHECK OF CR-15 AND S-4
22	12-006	393	5-73	6-73	CONTROL	-300	DNF		MK 127 SWITCH S-2 DEFECTIVE	(1) SWITCH DID NOT CLOSE (2) COCKED POST
23	11-034	531	5-73	9-73	THERMAL SHOCK	+195	FOA			(1) DATA INDICATE V-5 CONDUCTED AT ROTOR ARMING
24	11-035	407	6-73	7-73	THERMAL SHOCK	+195	FOA			(1) DATA INDICATE V-5 CONDUCTED AT ROTOR ARMING
25	12-011	456	7-73	7-73	THERMAL SHOCK	-300	DNA		C-5 DEFECTIVE	(1) C-5 WOULD NOT HOLD CHARGE (2) CR-10 HAD HIGH FORWARD RESISTANCE
26	11-040	583	8-73	9-73	VIBRA.	+195	DNA		STATOR CONTACT DEFECTIVE	(1) #11 & 13 CONTACTS LOOSE (2) C-8 WAS ZERO VOLTS AFTER TEST (3) POOR QUALITY CONTROL
27	11-040	593	8-73	9-73	THERMAL SHOCK	+195	LG ARM	8.32	CR-19 DEFECTIVE R-14 DEFECTIVE	(1) R-14 CIRCUIT RESISTANCE HIGH (2) FATE TIME LONG – 8.44 SEC (3) POOR QUALITY CONTROL (4) CR-19 HAD LOW REVERSE RESISTANCE
28	12-016	622	8-73	10-73	THERMAL SHOCK	+195	DNA		MK 127 SWITCH INSULATION CR-8 DEFECTIVE	(1) S-1 SHORTED TO GROUND (2) POOR QUALITY CONTROL
29	12-020	793	11-73	1-74	VIBRA.	-300	FOA			(1) DATA INDICATE POSSIBLE MK 128 CLOSURE AND C-8 FIRED S-4
30	12-020	795	11-73	1-74	VIBRA.	+195	LG ARM	7.32	CR-17 DEFECTIVE CR-18 DEFECTIVE	(1) C-9 HAD LEAK PATH TO C-5 (2) CR-15 S-4 CIRCUIT OPEN (NO S-4 OPEN CONTACTS) (3) CR-18 HAD HIGH FORWARD RESISTANCE (4) CR-17 HAD HIGH LEAKAGE
31	11-046	755	11-73	1-74	VIBRA.	-300	DNF		CR-18 DEFECTIVE	(1) CR-18 HAS LOW REVERSE RESISTANCE
32	11-046	766	11-73	1-74	THERMAL SHOCK	-300	DNA		CR-4 DEFECTIVE	(1) CR-4 SHORTED
33	11-008	129	10-72	11-72	VIBRA.	+195				(1) OPTION FAILURE (2) S-1 DID NOT FIRE
34	11-031	676	4-73	10-73	THERMAL SHOCK	+195			CR-5 DEFECTIVE	(1) LOW INPUT RESISTANCE AT NEGATIVE VOLTAGE
NOTE	(1) LG ARM – LONG ARMING TIME, (2) DNA – DID NOT ARM, (3) DNF – DID NOT FIRE, (4) FOA – FIRED ON ARMING, (5) AOC – ARMED ON CHARGE, (6) ITEMS 33 & 34 SHOW COMPONENT FAILURE.									

TABLE 2

COMPUTED PROBABILITIES AND CONFIDENCE INTERVALS FOR COMPONENTS IN THE MK 344 FUZE

I	Component Name	Probability Symbol	Computed Probability	Confidence Interval
0	Option Circuit	P_o	251/252	(.990, 1)
1	Switch SW-1	P_1	167/168	(.987, 1)
2	Switch SW-2	P_2	251/252	(.990, 1)
3	Rectifier and Regulator	P_3	83/84	(.978, .998)
4	Arming Switches (2)	P_4	1	(1, 1)
5	Impact Switches or Mk 43 TDD	P_5	167/168	(.987, 1)
6	Detonator	P_6	1	(1, 1)
7	Switch SW-4	P_7	503/504	(.994, 1)
8	Energy Storage A (Arming and Detonation)	P_8	167/168	(.987, 1)
9	Energy Storage D (Detonation)	P_9	503/504	(.994, 1)
10	Function Timer	P_{10}	83/84	(.978, .998)
11	Arming Timer TA_1	P_{11}	1	(1, 1)
12	Arming Timer TA_2	P_{12}	1	(1, 1)
13	Bellows	P_{13}	1	(1, 1)
14	Mk 31 Safety Device	P_{14}	503/504	(.994, 1)
15	Switch SW-3	P_{15}	1	(1, 1)
16	Dudding Switches	P_{16}	1	(1, 1)
f	Compensating Factor	P_f	163/168	(.955, .985)

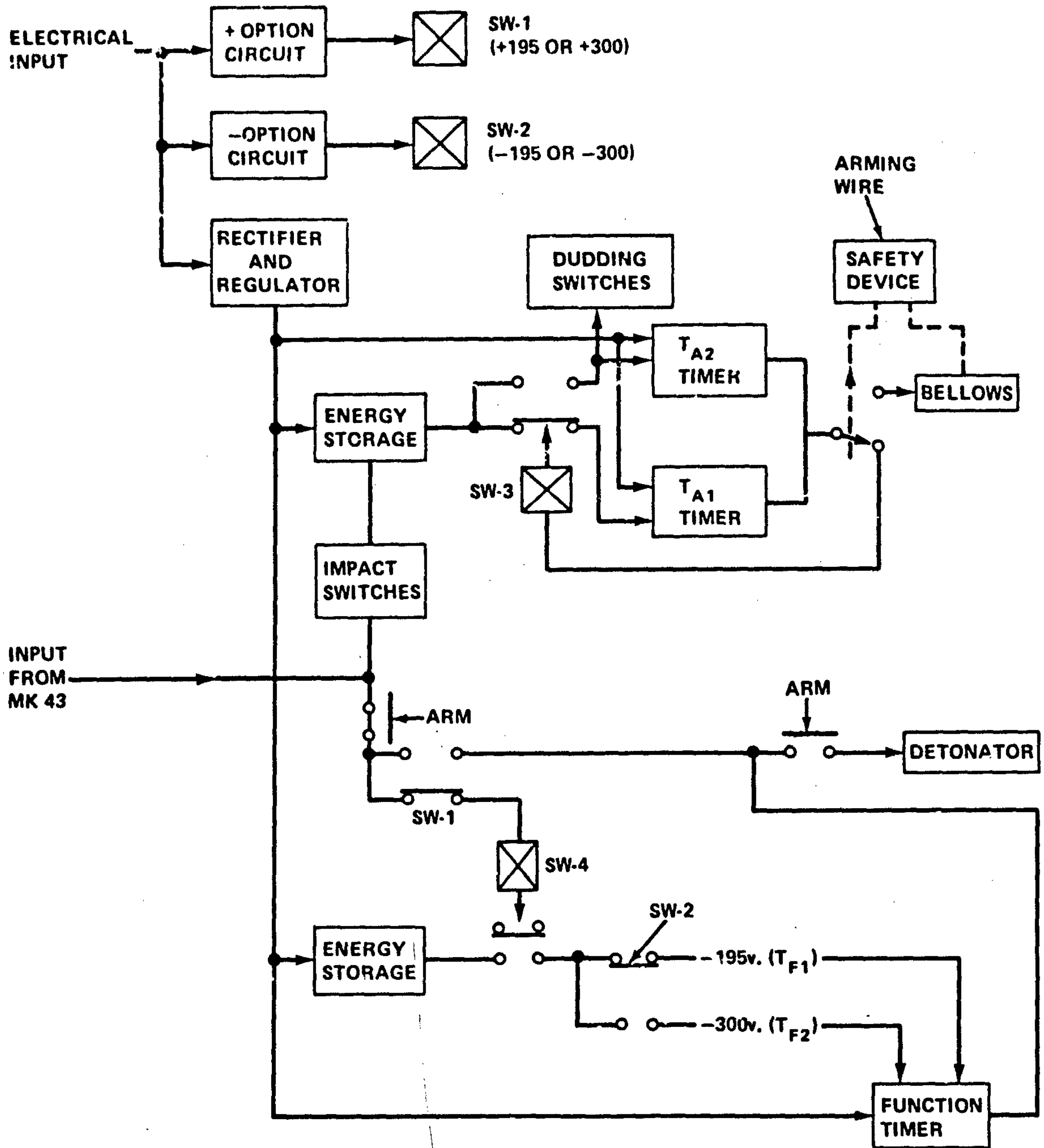

FIG. 1 FUNCTIONAL BLOCK DIAGRAM OF MK 376 MOD 0 FUZE

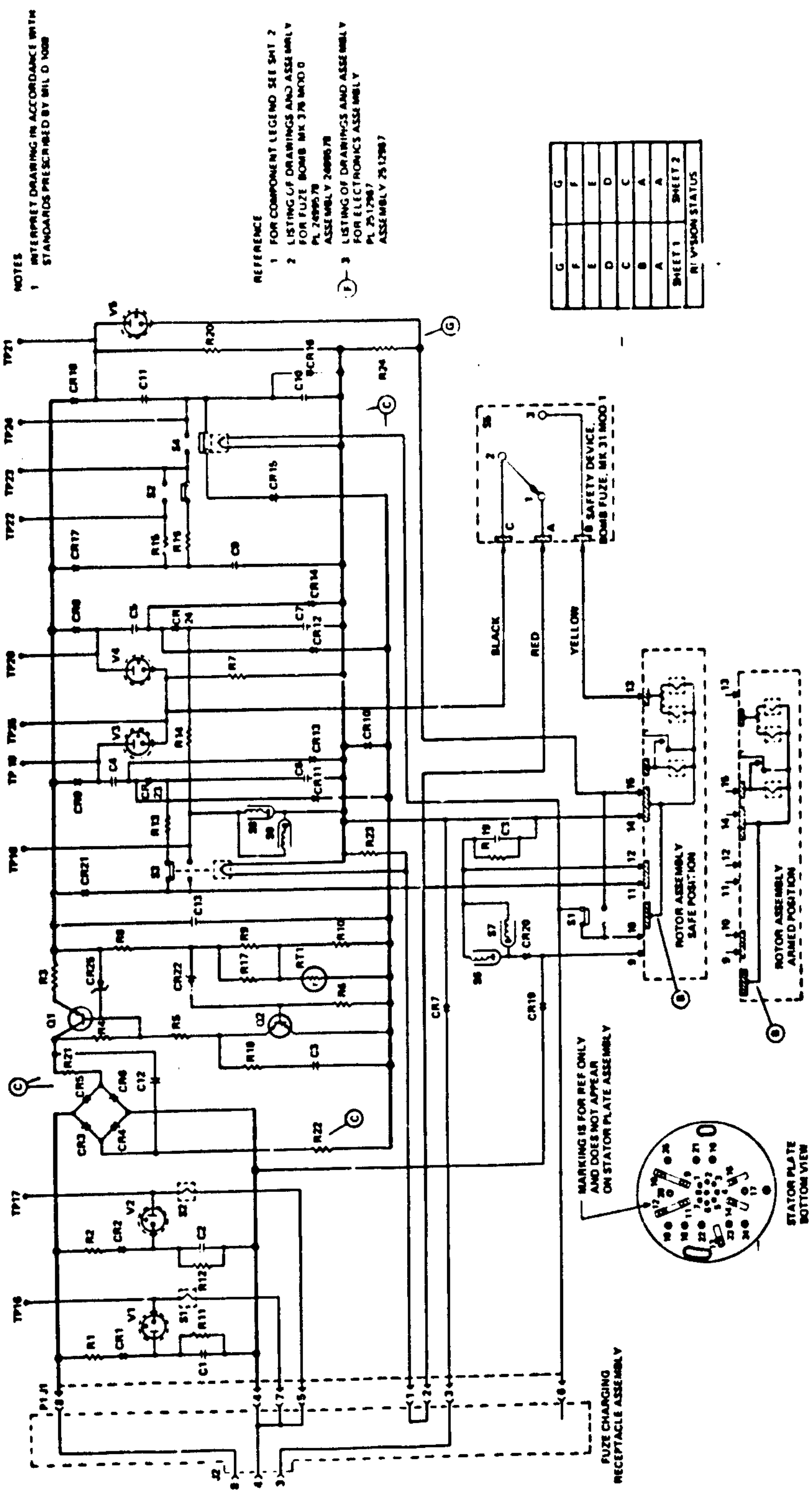

FIG. 2 CIRCUIT DIAGRAM OF MK 376 MOD 0 FUZE

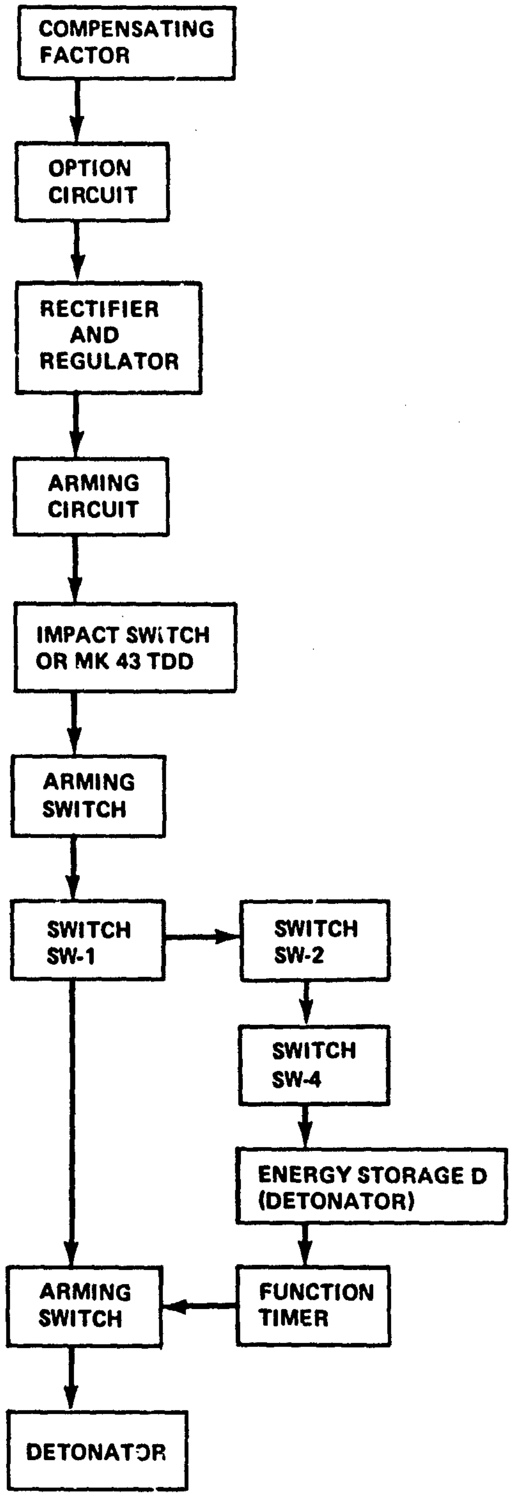

FIG. 3 LOGICAL PATHS TO DETONATION

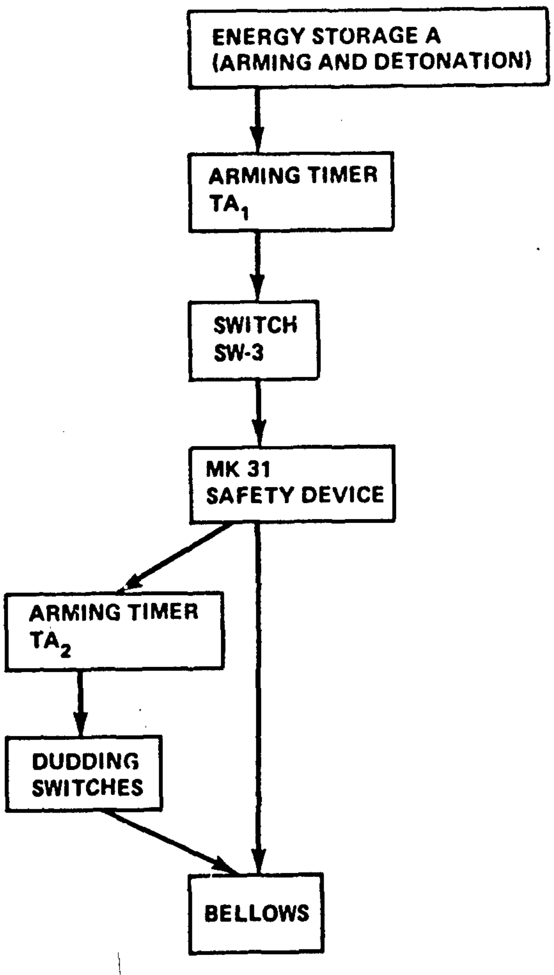

FIG. 4 ARMING CIRCUIT LOGICAL FLOW DIAGRAM

APPENDIX

NUMERICAL RESULTS

In this section, we show how to calculate the reliability of the Mk 344 Mod 1 fuze on the basis of the data given in Table 1 and how to obtain an approximate 95.4% confidence interval from this information. From each lot shown in this table,a sample of 24 fuzes was drawn, of which ten were subjected to thermal shock, ten to vibration, and four to no treatment. The fuzes were subjected to simulated drop tests. Also, when a lot number appears with two letter designations (11-018A and B in the table), it should be understood that the A sample of 24 did not meet the specifications and so another sample of 24 with a B designation was drawn from the same lot. It is seen that there are 21 sets of 24, making a total of 504 fuzes tested. Table 2 lists the components by name and number designation, together with their frequencies of success (in the 504 simulated drops) and associated confidence intervals (to be described). One must remember that, for the Mk 344 Mod 1 fuze, arming timer TA_1, switch SW-3, and the dudding impact switches are not included in the fuze circuitry. Thus their probabilities are given as 1 in the table. Note, also, that there were no failures attributed to the two arming switches, the detonator, and the bellows. From formula (1), we see that we must multiply the tabular frequencies to get our reliability, which is readily seen to be .918. If we examine Table 1, we also find that the overall success ratio is just 470/504 = .933. We see that these two figures are in good statistical agreement.

We show now how to obtain an approximate 95.4% confidence interval. We shall follow Hogg and Craig[4] and do our analysis in two ways. Our first procedure will be to assume a binomial distribution for success of the fuze. W are looking for an interval which, with 95.4% certainty, contains the fuze reliability. When n is sufficiently large, we are able to assert that the random variable

$$Z_n = (Y - np)/\sqrt{n(Y/n)(1-Y/n)},$$

where Y is the number of successful simulated drops, is approximated by a normal random variable with mean 0 and variance 1. On this basis, we see, from standard tables of the normal distribution, that

$$\Pr[-2<Z_n<2] = .954. \qquad (2)$$

[4] Robert V. Hogg and Allen T. Craig, Introduction to Mathematical Statistics Third Edition, MacMillan, 1970, pp. 196-198

Now Z_n can be rewritten as

$$Z_n = \frac{(Y/n)-p}{\sqrt{(Y/n)(1-Y/n)/n}},$$

and so (2) can be recast in the form

$$\Pr\left[\frac{Y}{n} - 2\sqrt{\frac{(Y/n)(1-Y/n)}{n}} < p < \frac{Y}{n} + 2\sqrt{\frac{(Y/n)(1-Y/n)}{n}}\right] = .954. \tag{3}$$

The advantage of the form (3) is that we now have at our disposal a confidence interval for p, the fuze reliability, directly in terms of the success ratio Y/n. We have found that the interval

$$\left(\frac{y}{n} - 2\sqrt{\frac{(y/n)(1-y/n)}{n}}\ ,\ \frac{y}{n} + 2\sqrt{\frac{(y/n)(1-y/n)}{n}}\right) \tag{4}$$

is an approximate 95.4% confidence interval for p. To obtain our confidence interval on the basis of the Fairchild data, we simply substitute our success ratio of .933 and our value of $n = 504$ into (4) to obtain (.910, .955). Therefore, by procedure 1, with 95.4% certainty, the fuze reliability lies between .910 and .955. Our fuze is, on this basis, at least 91% reliable. Our second procedure will be to treat each component as a binomially distributed random variable and to obtain a confidence interval on the basis of component successes. Since formula 1 indicates that we multiply all our component probabilities together to obtain fuze reliability, we must similarly multiply our component confidence intervals to obtain an overall confidence interval for the fuze. Therefore, we use the success ratios provided by Table 2 in (4) to obtain the confidence intervals as shown in the last column. Multiplying all the left endpoints together, we obtain a figure of .848; and, multiplying the right endpoints, a figure of .981. This gives a 95.4% confidence interval of (.848, .981), which is seen to be in good statistical agreement with our first interval of (.910, .955).

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